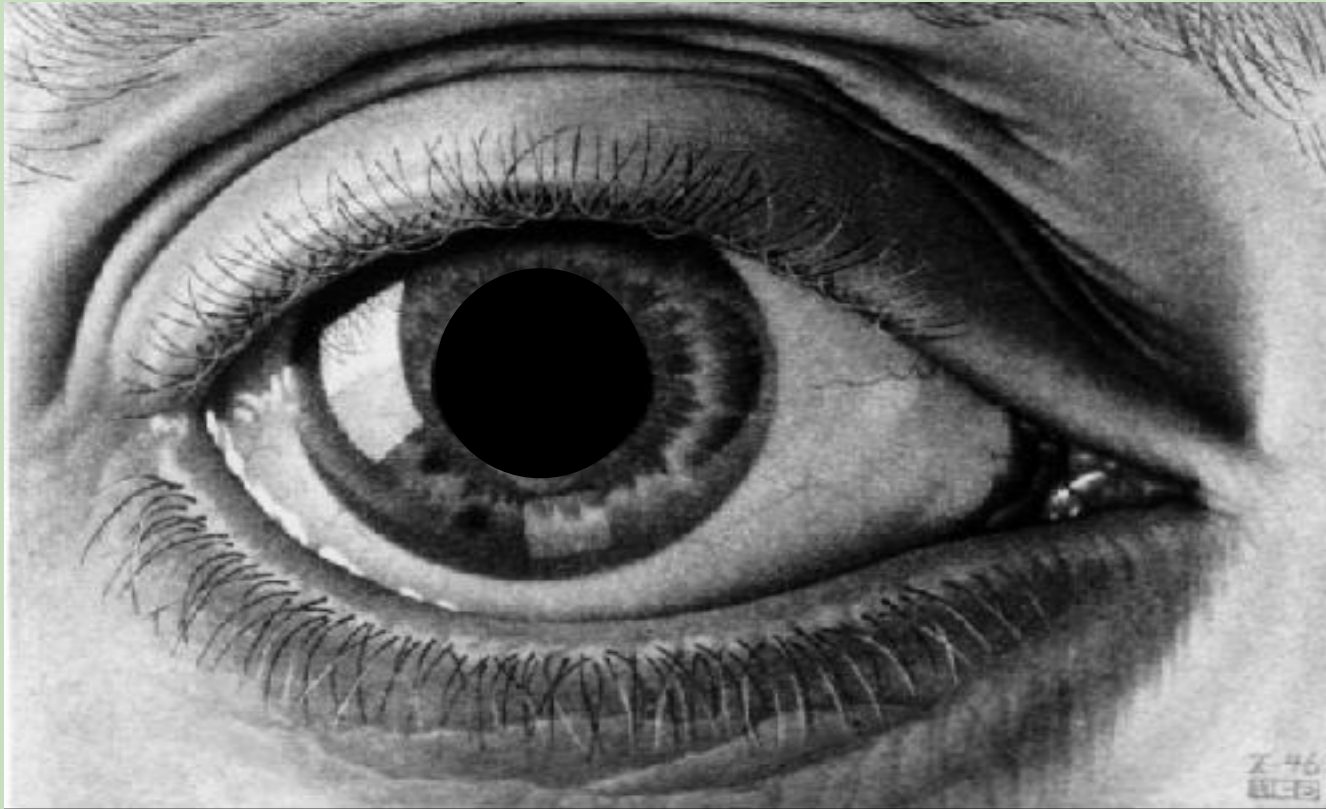


Use of the Free Electron Laser for the Noninvasive Determination of Retinal Oxyhemoglobin Saturation by Near Infrared Reflectance Spectrophotometry

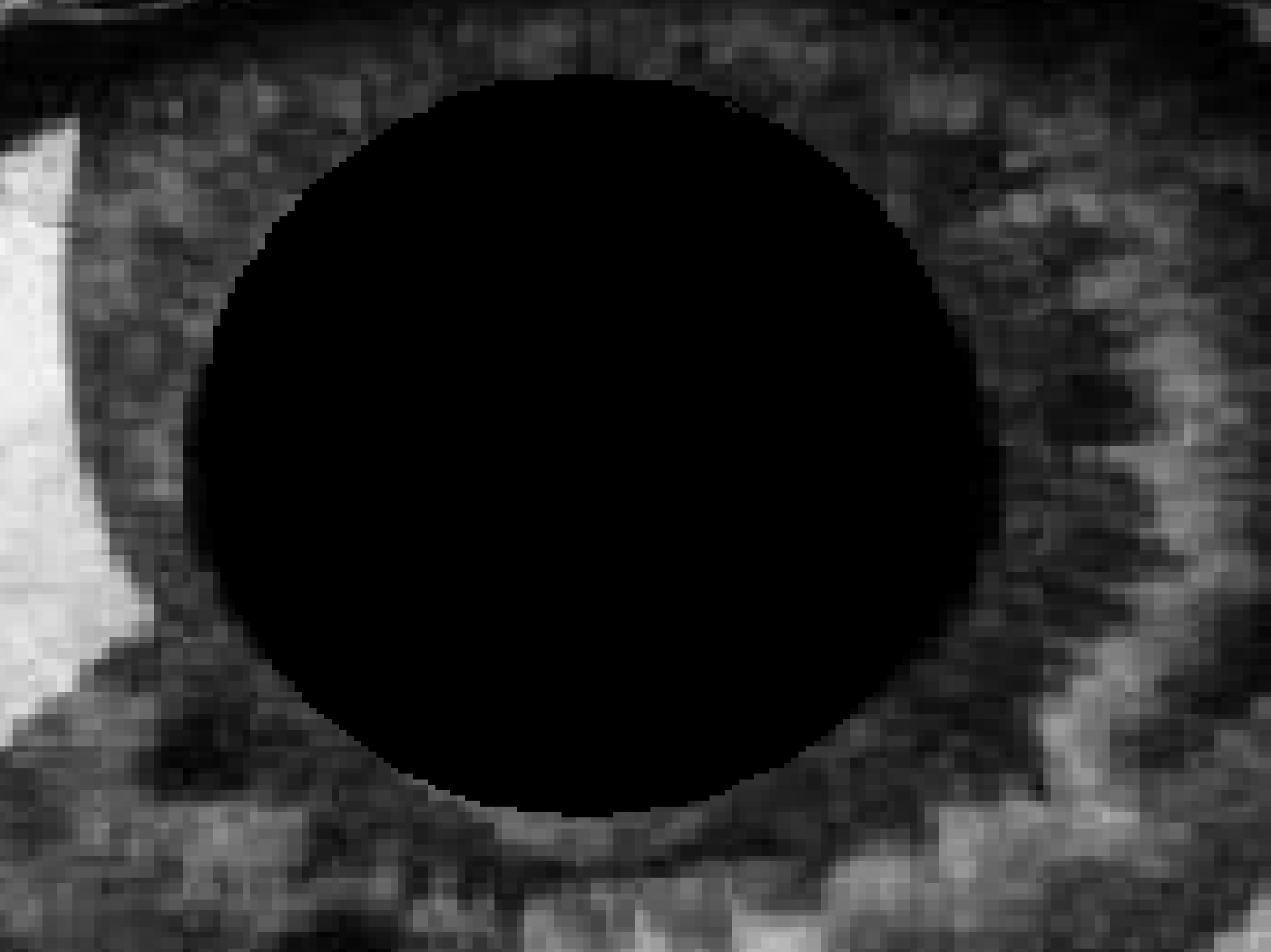




Ref: Eye, M.C. Escher, 1946









Why Is It Important to Determine Retinal Oxygenation ?

Several Types of Ischemic Retinopathies:

Arterial Occlusion
Venous Occlusion
Ocular ischemic syndrome
Retinopathy of prematurity
Diabetic retinopathy



2000 National Estimates of the Burden of Diabetes

Diabetes Prevalence:

**Diagnosed
Undiagnosed
Total**

**11.1 million
5.9 million
17.0 million (6.2% of US population)**

Diabetic Retinopathy Prevalence:

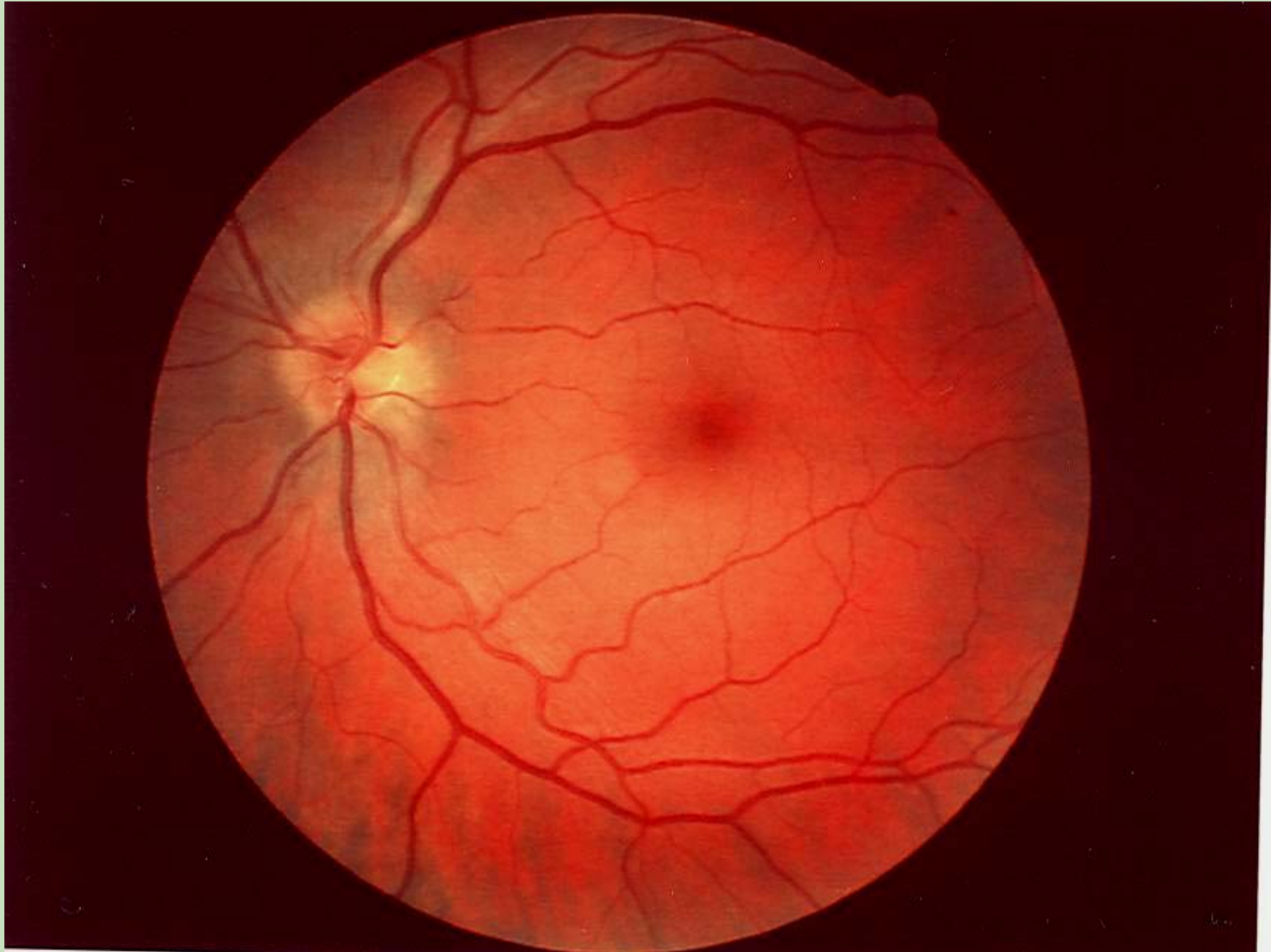
**65,000 diabetics per year
develop proliferative DR**

**Leading cause of blindness
among 20 to 74 yr old**

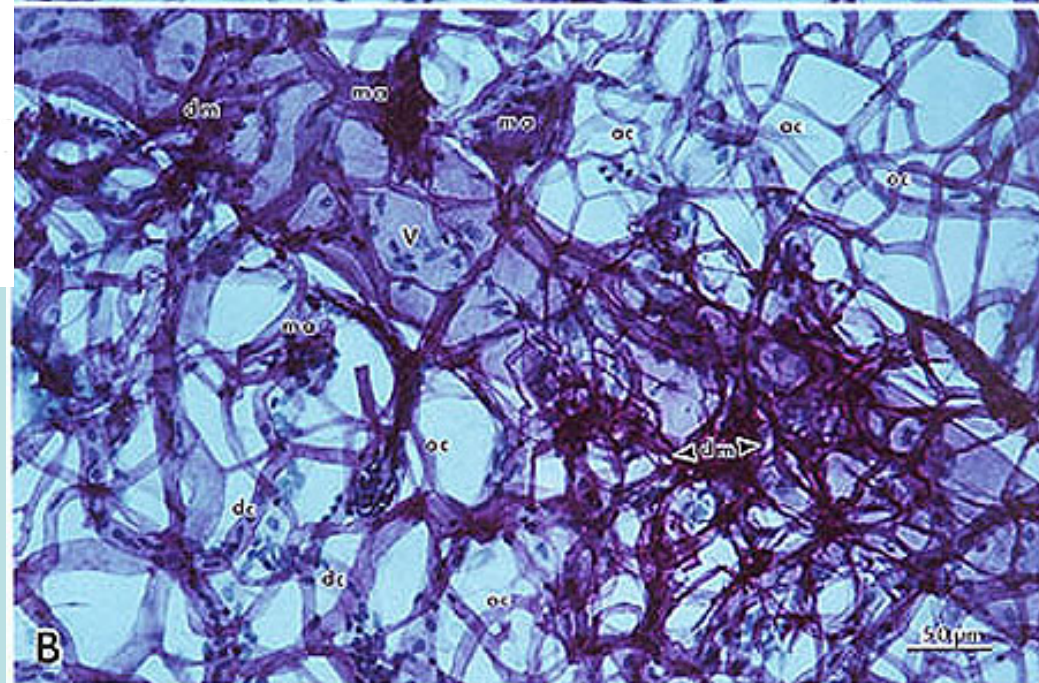
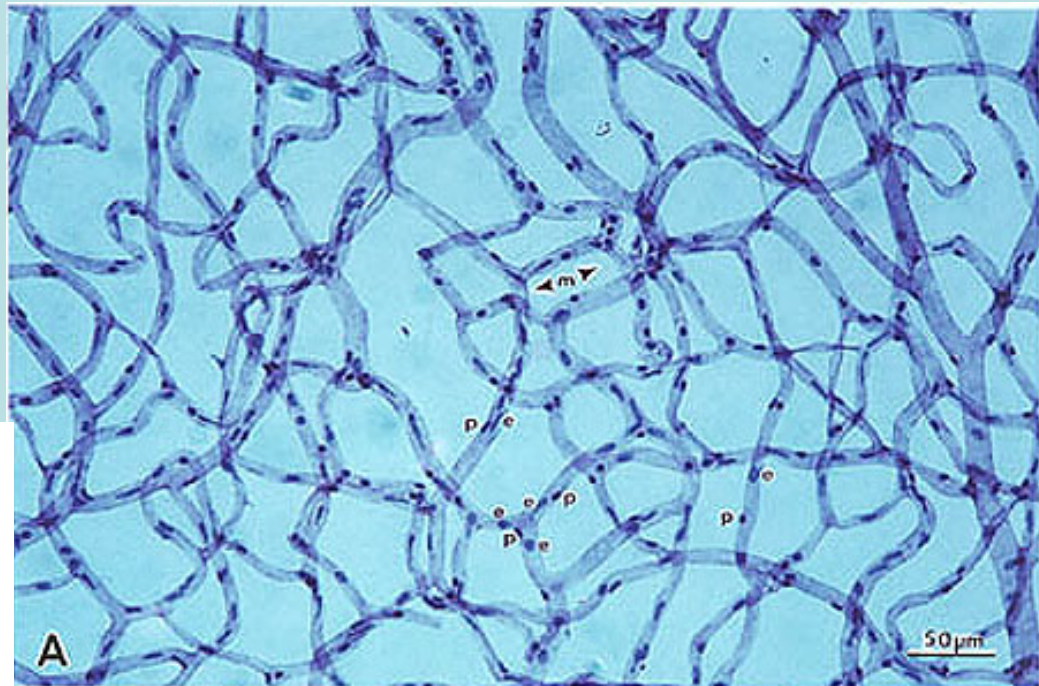
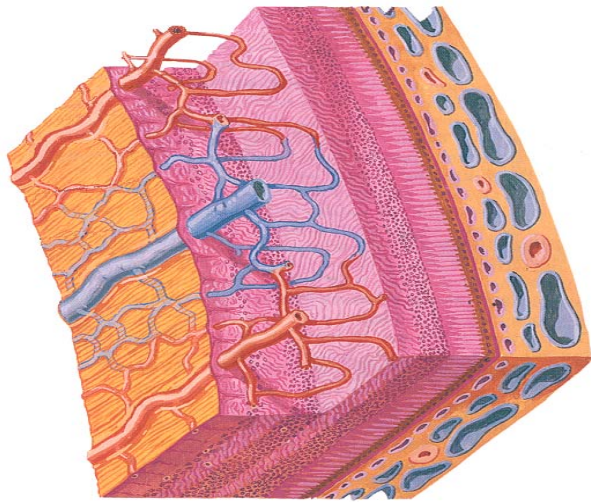
Ref: National Diabetes Information Clearinghouse
Research to Prevent Blindness

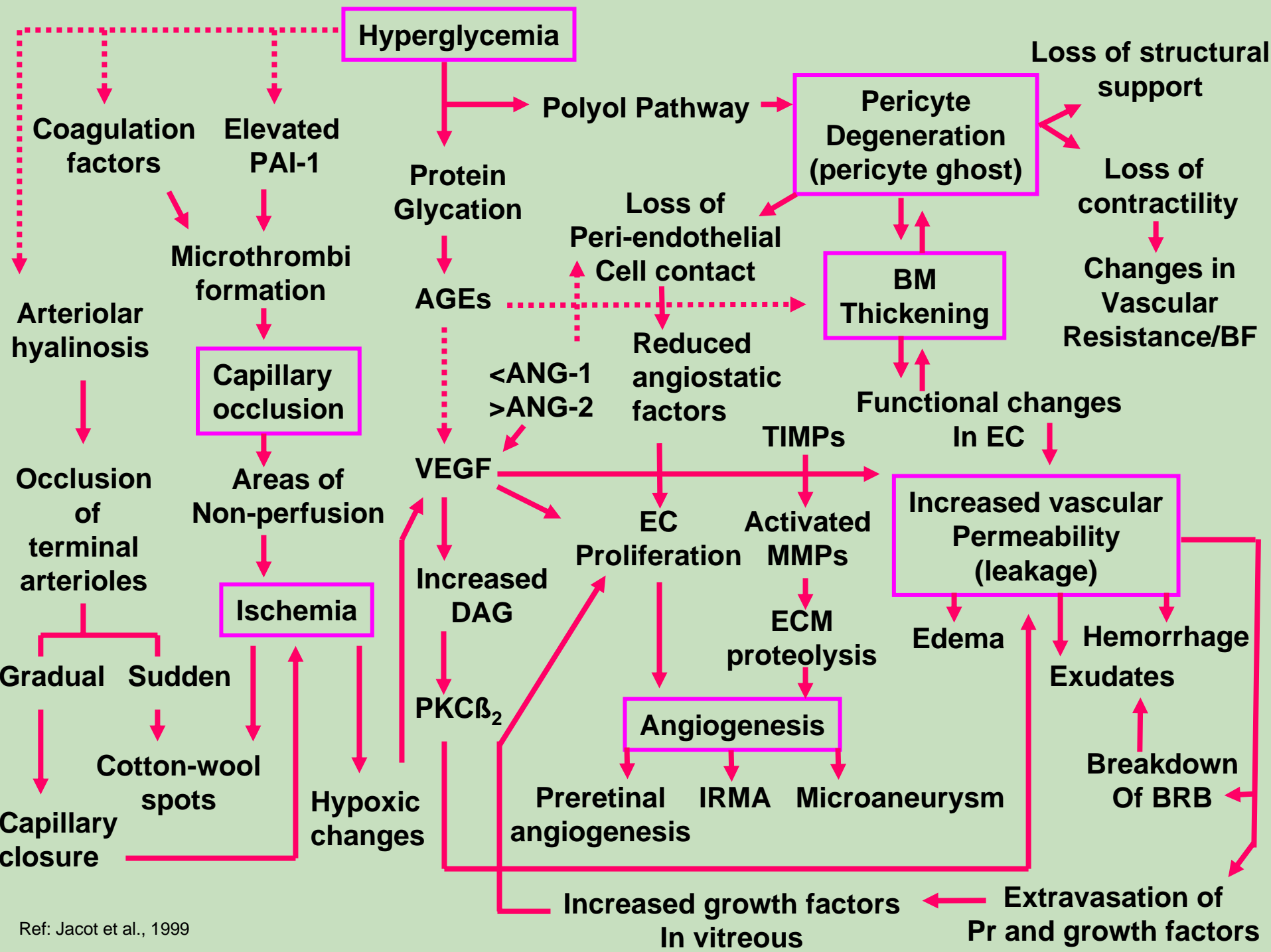


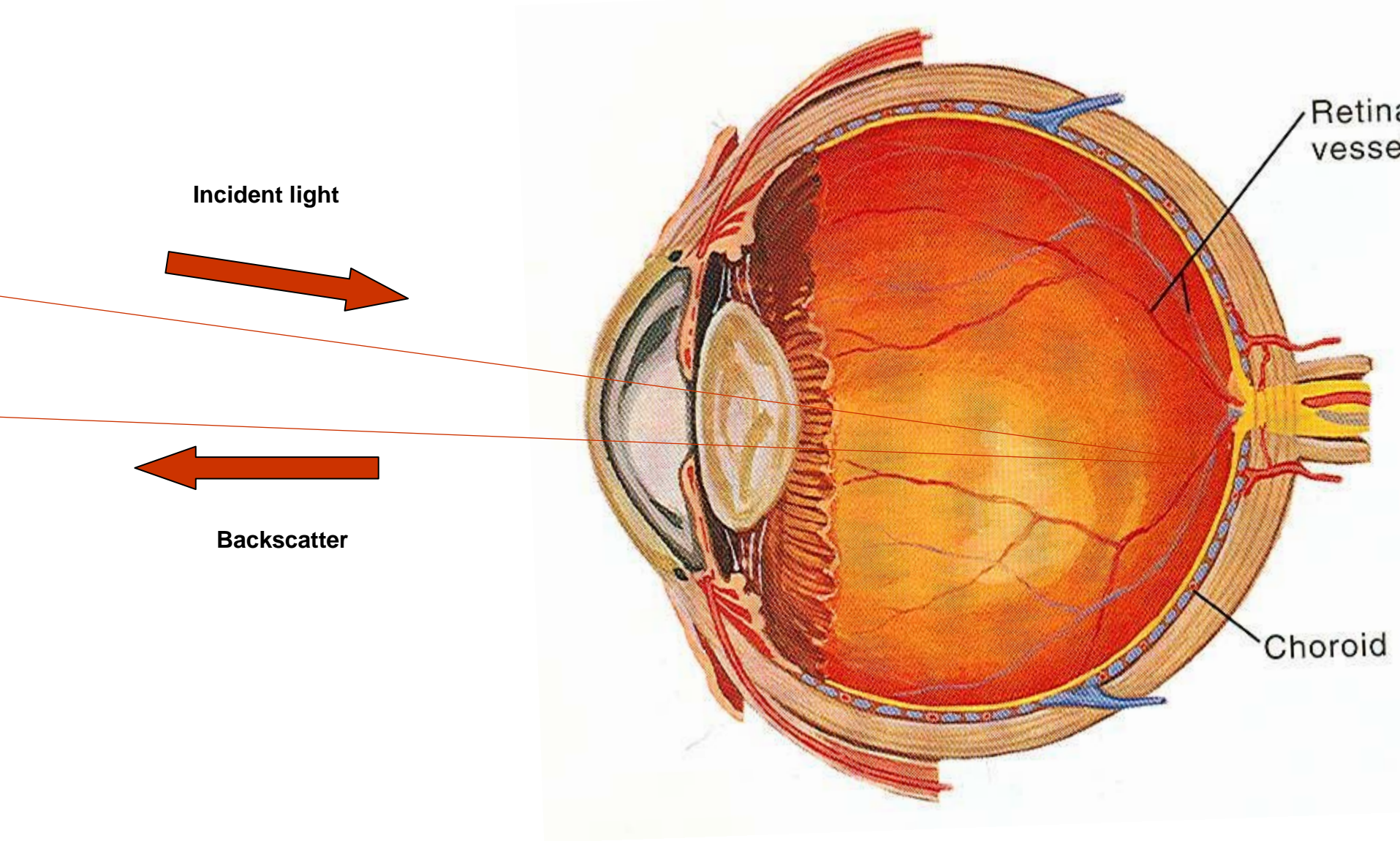
Diabetic Retinopathy







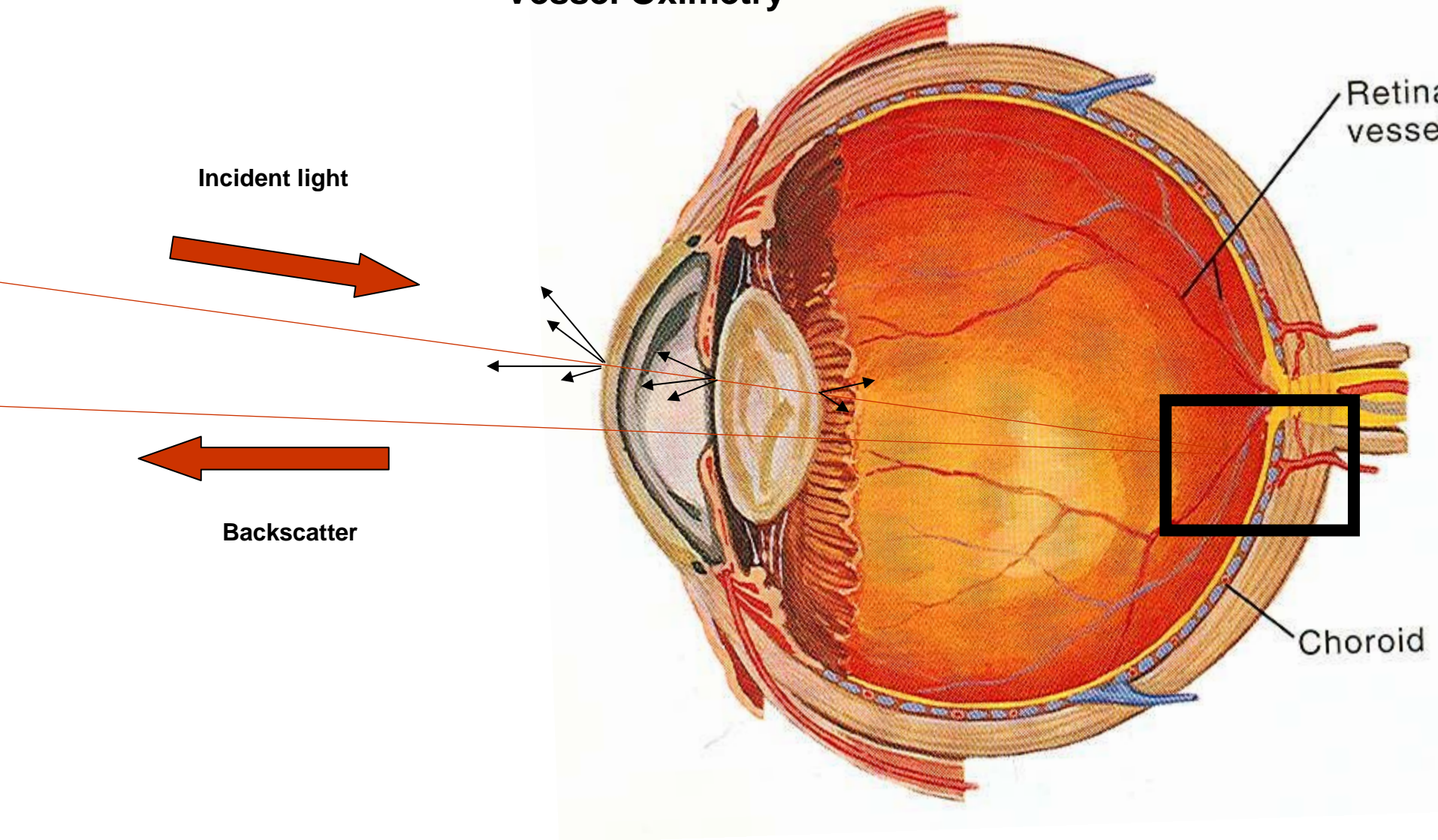




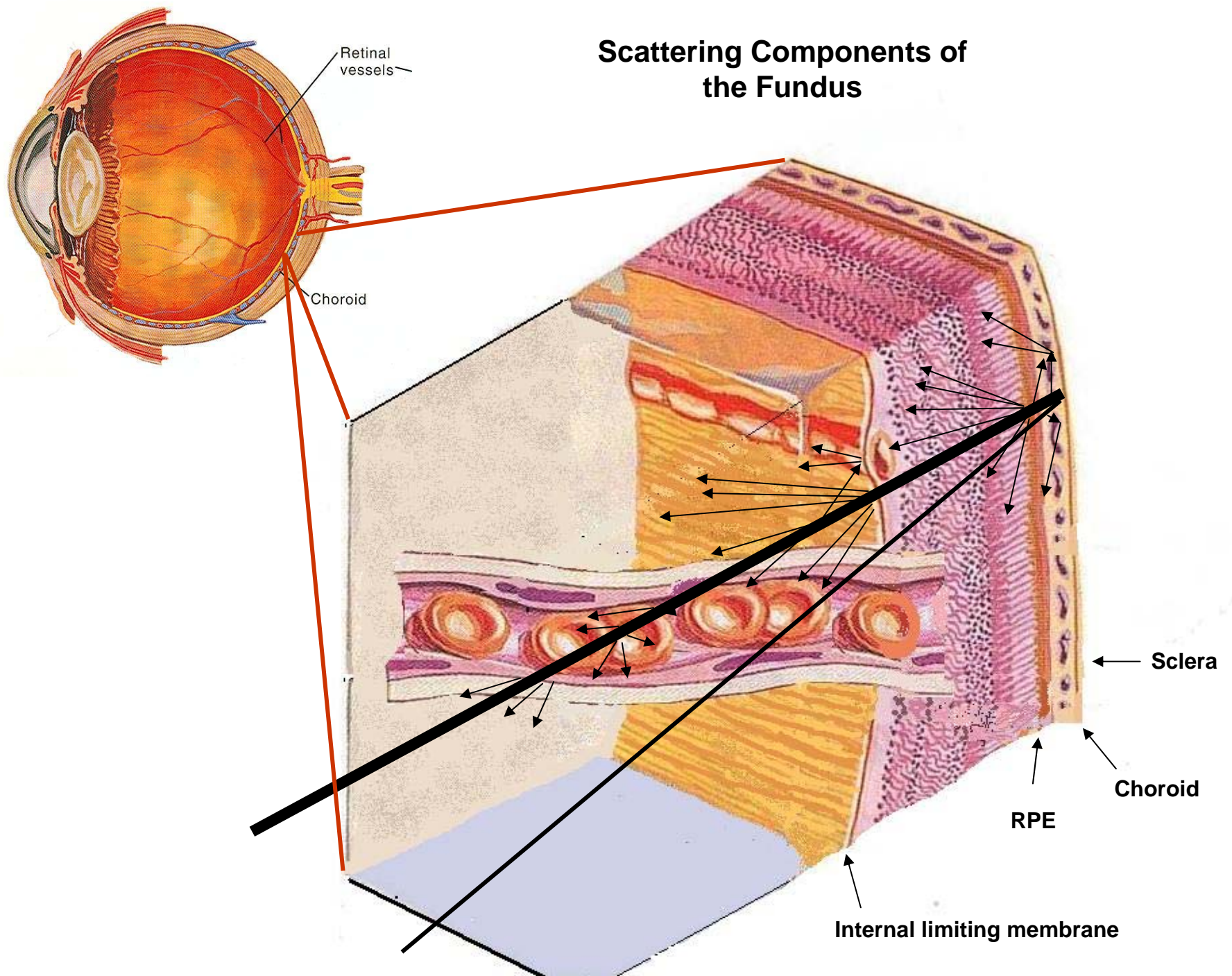
Favorable Attributes of the FEL

- Short pulsation of the emitted light
 - » Minimizes total retinal irradiance
 - » Compensates for eye movements

Vessel Oximetry



Scattering Components of the Fundus



Cornea
 $n=1.377$

Focal length
Approximately 23 mm
 $n= 1.427$

Vitreous humor
 $n = 1.336$

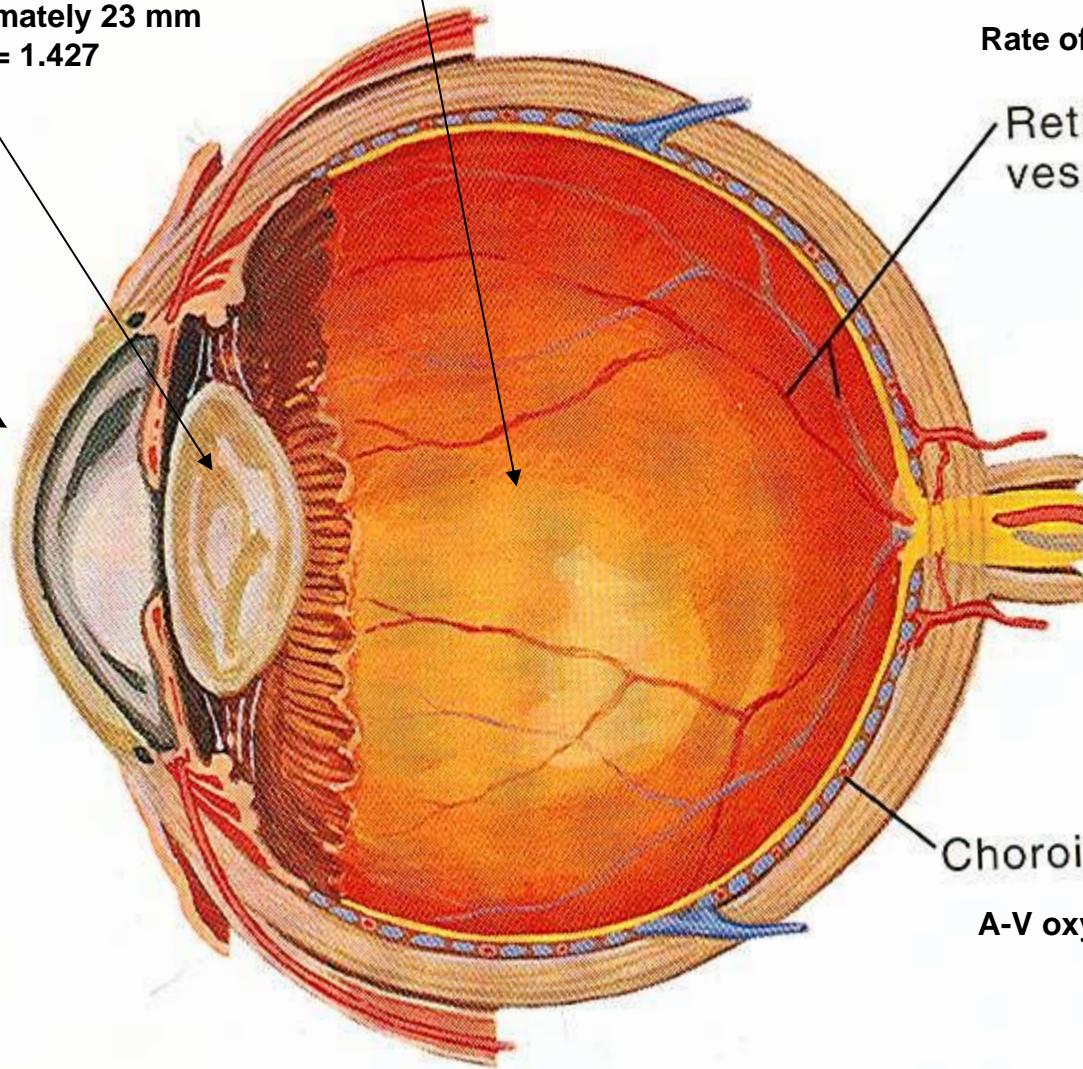
Diameter of Retinal Vessels:
Veins: 212 μm
Arteries: 150 μm

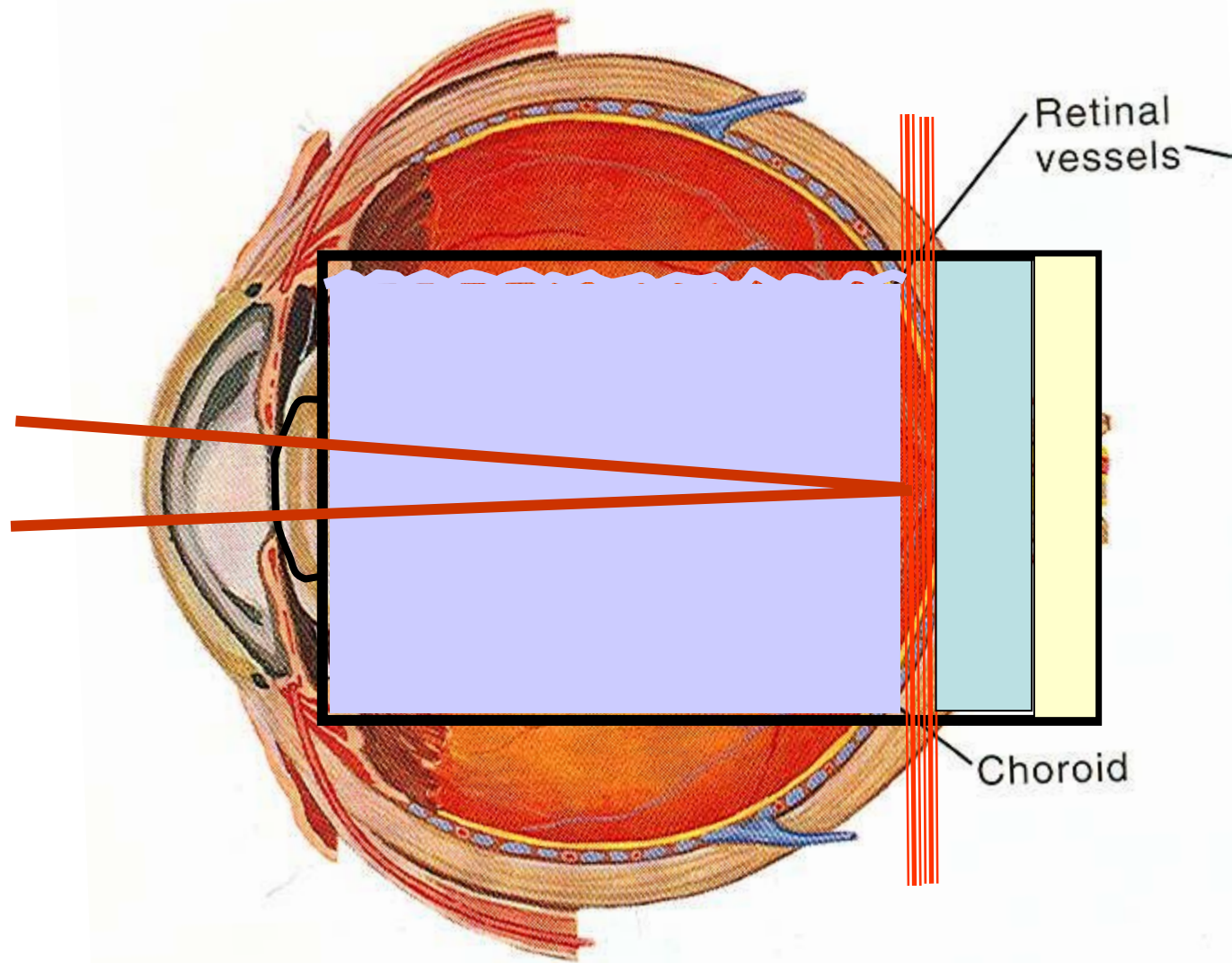
Rate of flow: 34 $\mu\text{l/min}$

Retinal vessels

Choroid

A-V oxygen difference 2%



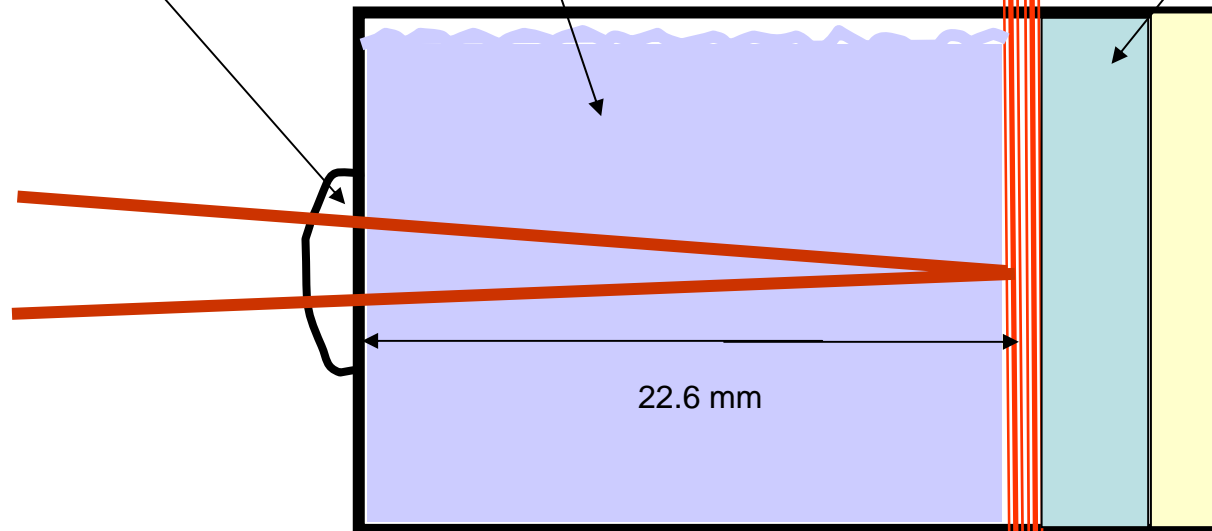


Vitreous
50% v/v Standard type A immersion oil $n = 1.515$
50% Mineral spirits $n = 1.438$
 $n = 1.476$

Cornea
 $f = 17.2 \text{ mm}$
Plano-convex lens

Retinal vessels
Capillary pipette Internal diameter 110-268 μm
Borosilicate glass $n = 1.472$

Phantom retina
Spectralon
Diffuse reflection

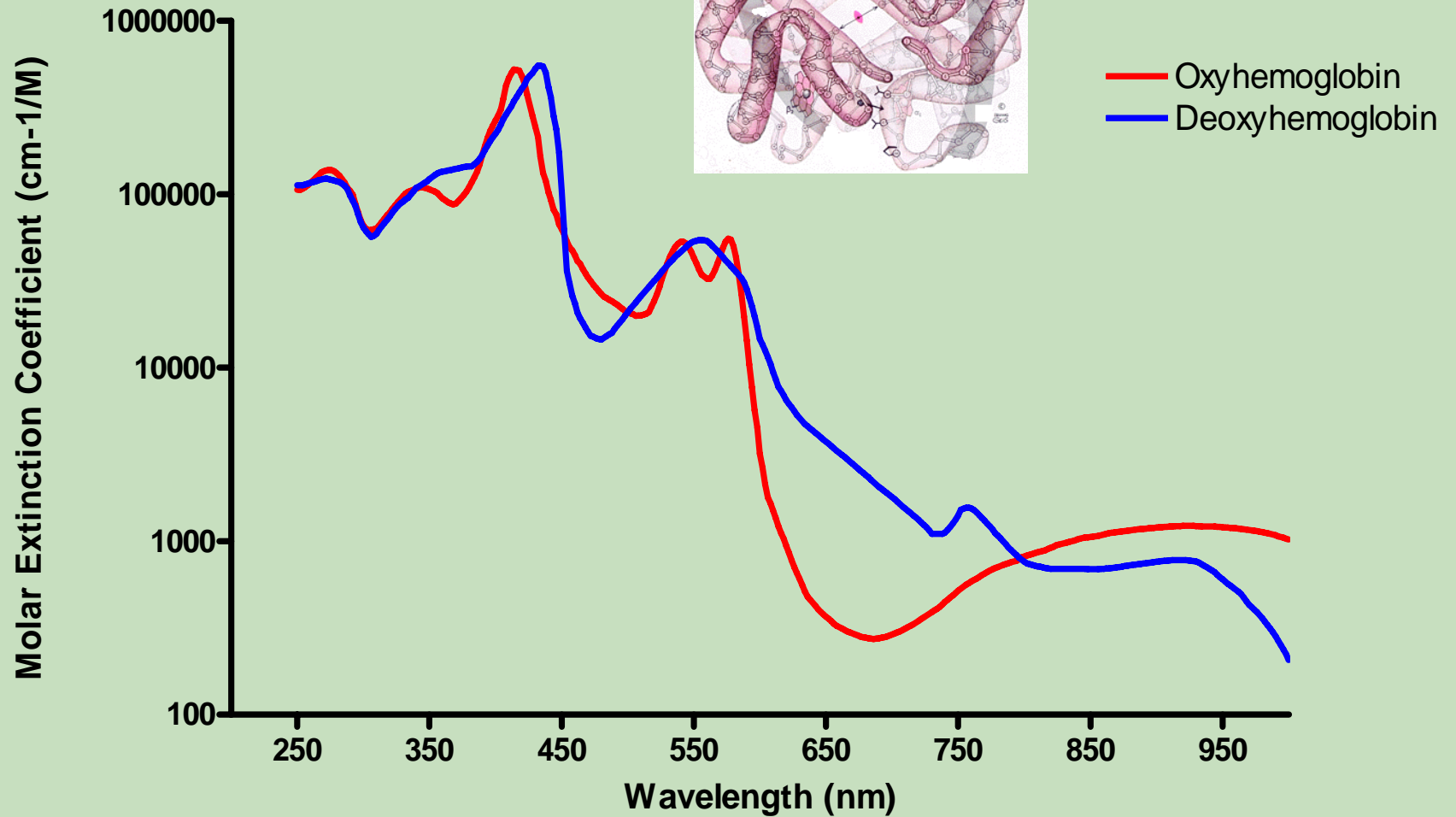


- Optical geometry
- Reflectance properties

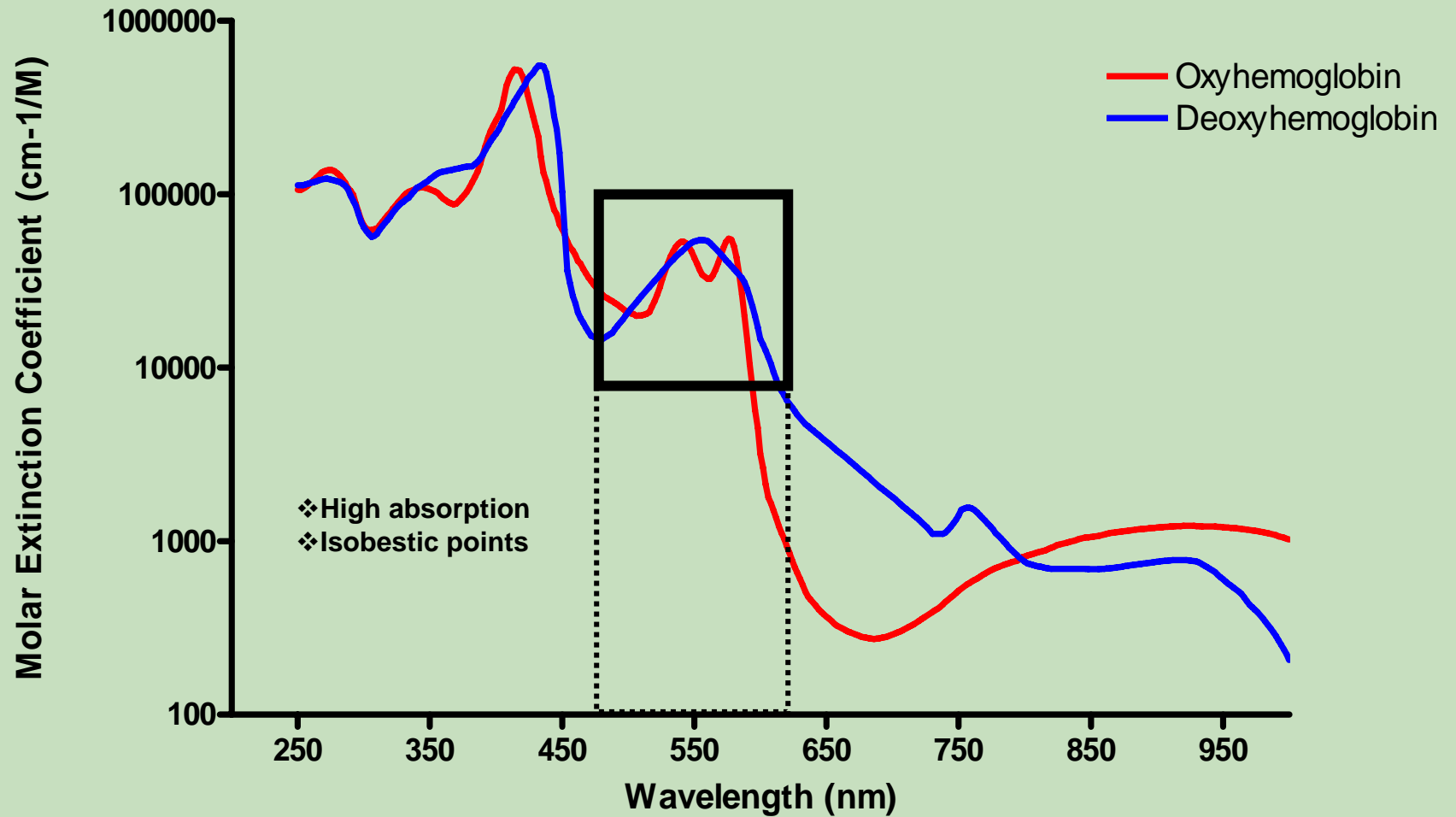
Rate of flow
34 $\mu\text{l}/\text{min}$

Aluminum Backing

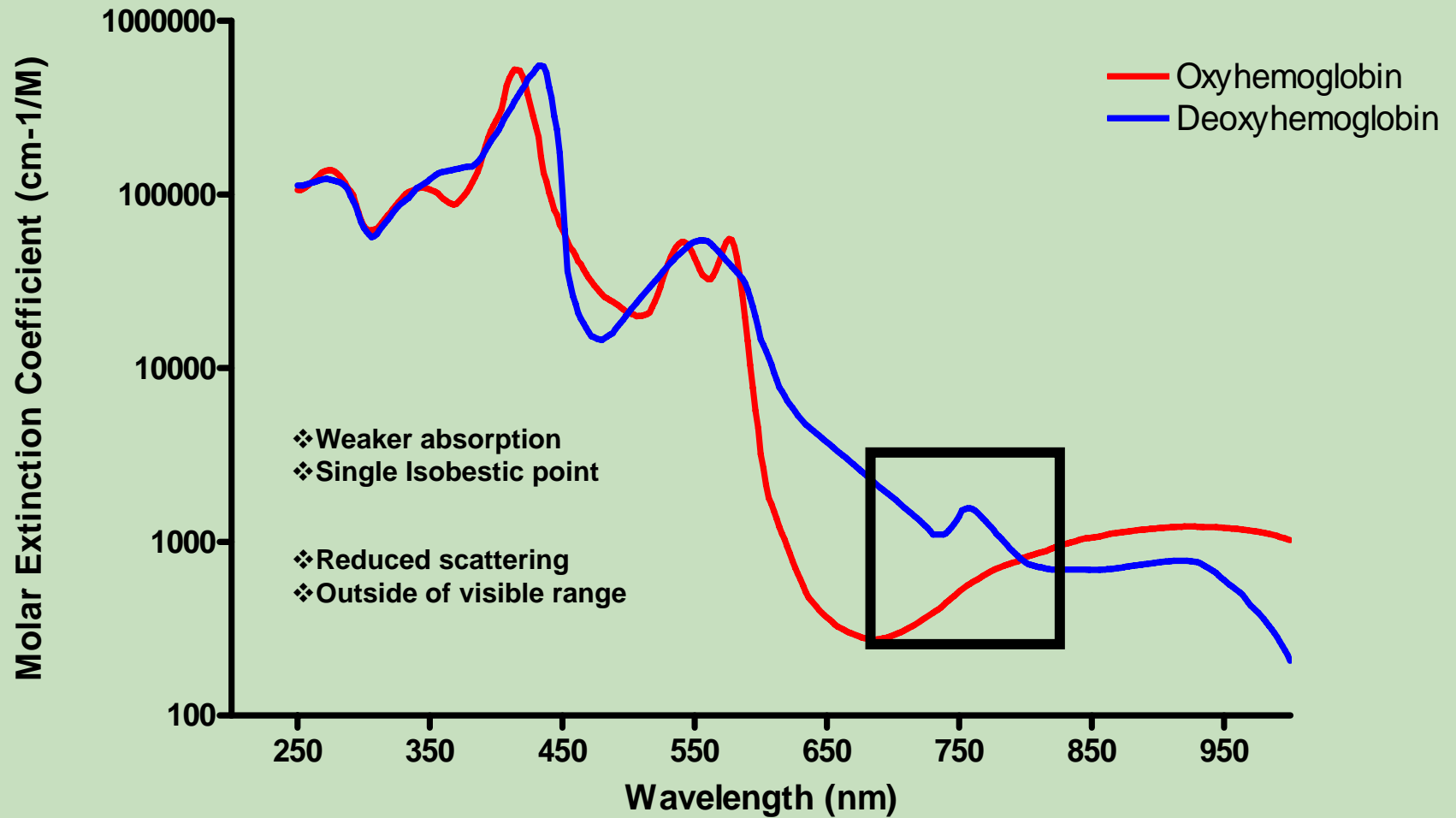
Optical Absorption of Hemoglobin



Optical Absorption of Hemoglobin



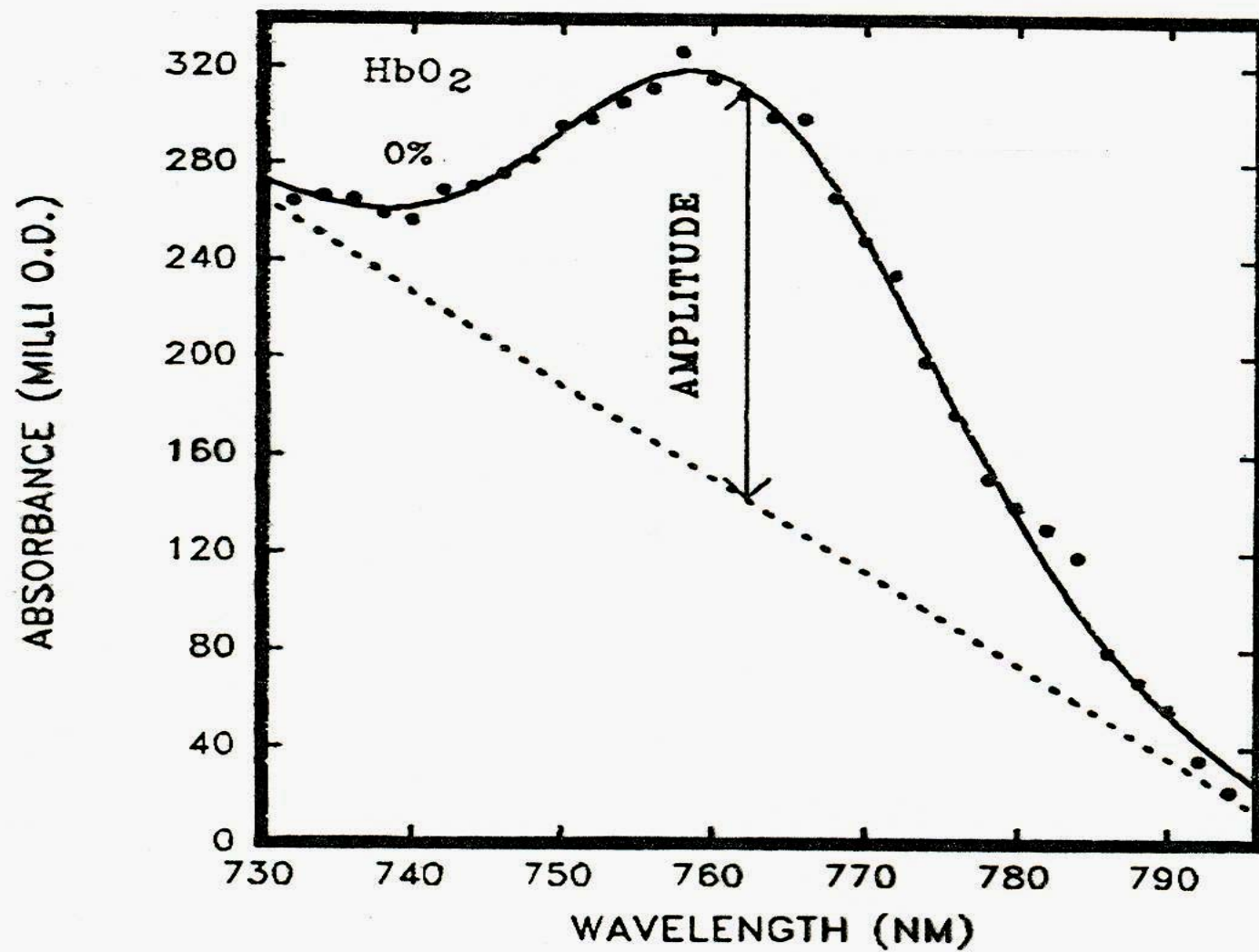
Optical Absorption of Hemoglobin

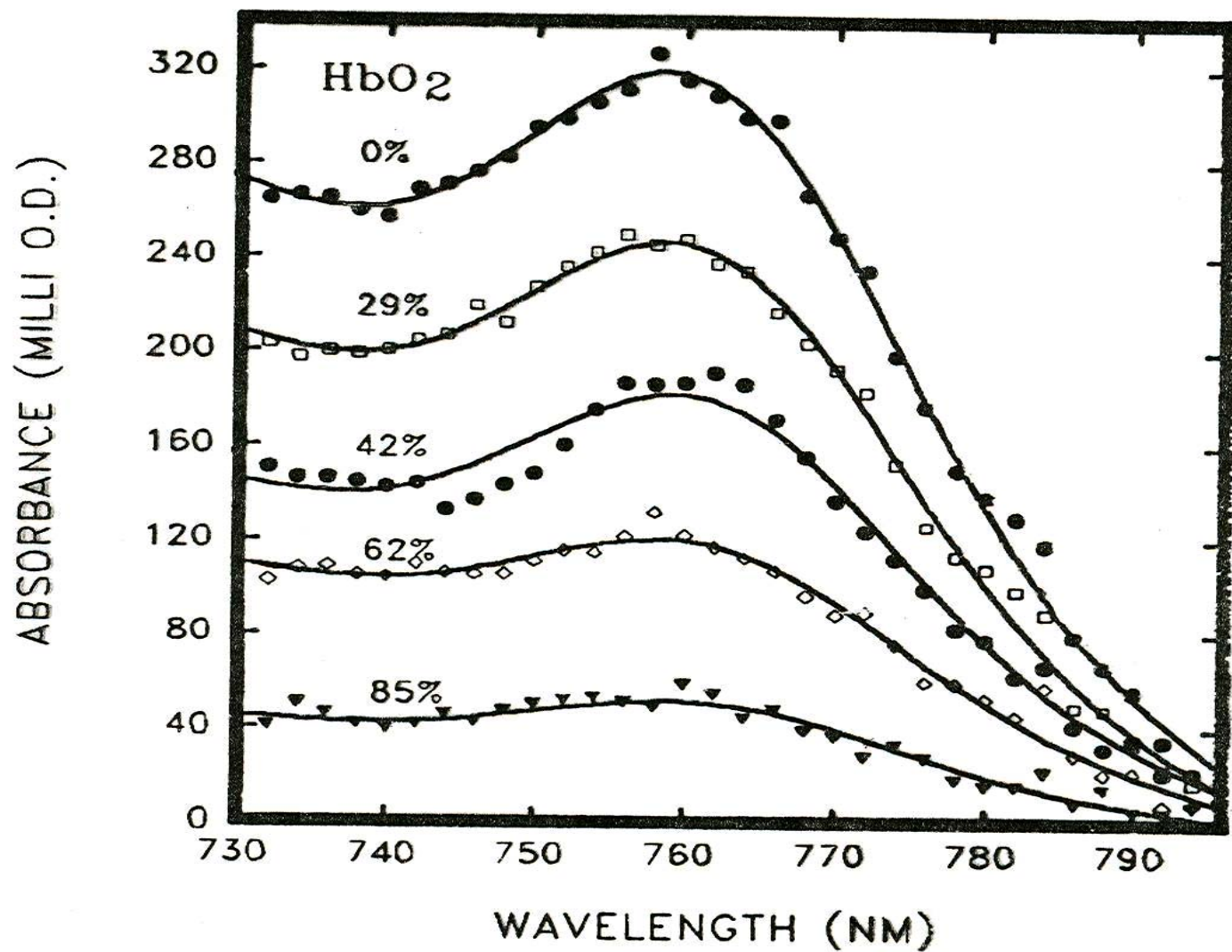


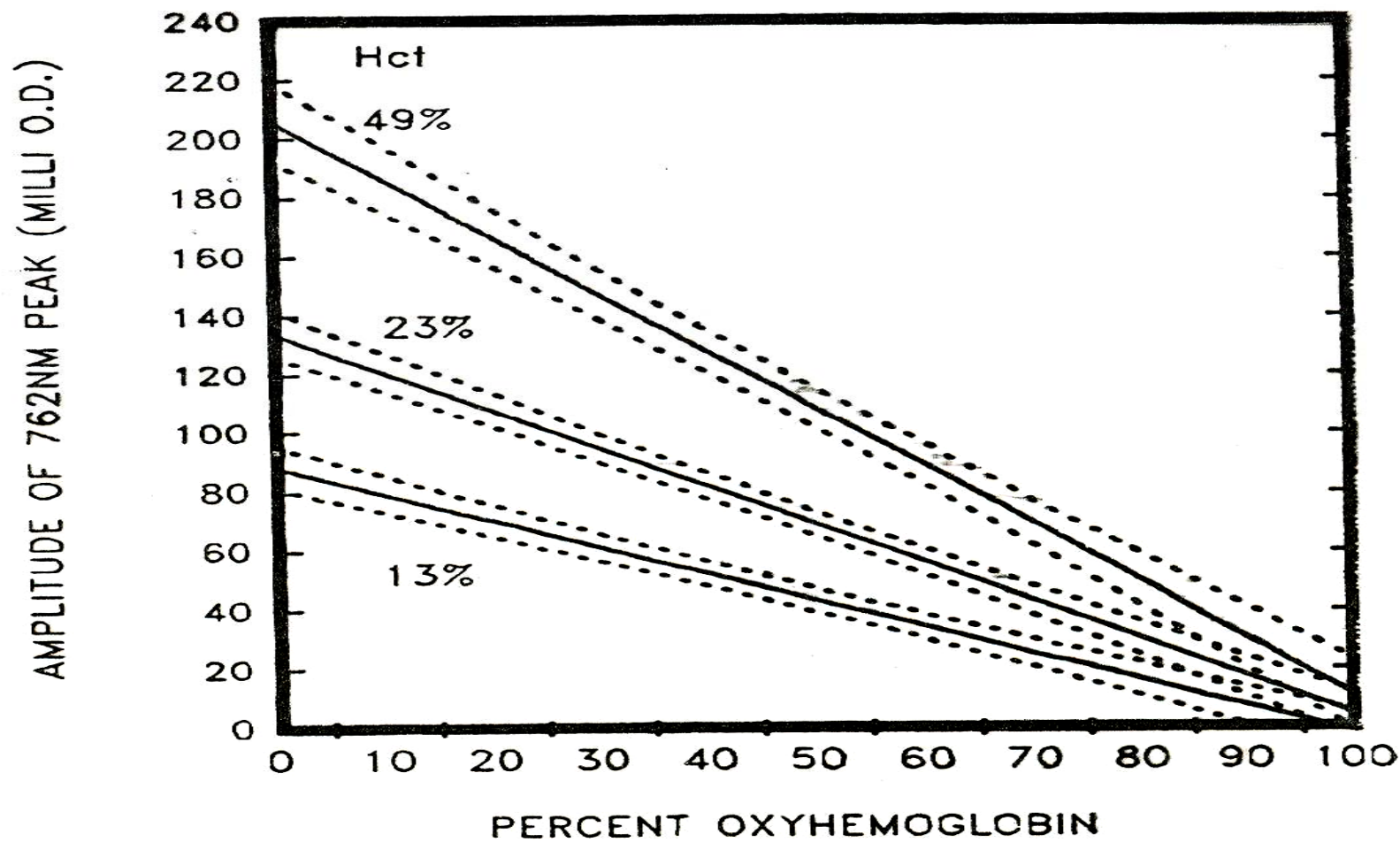
Favorable Attributes of the FEL

- Broad tunability of the emitted light.
 - » To rapidly scan a range of 70 to 100 nm
 - » Alternate between visible and near-infrared
- Strong energy output in the near-infrared region of the spectrum (700 to 900 nm).
 - » Where hemoglobin chromophore signal is attenuated





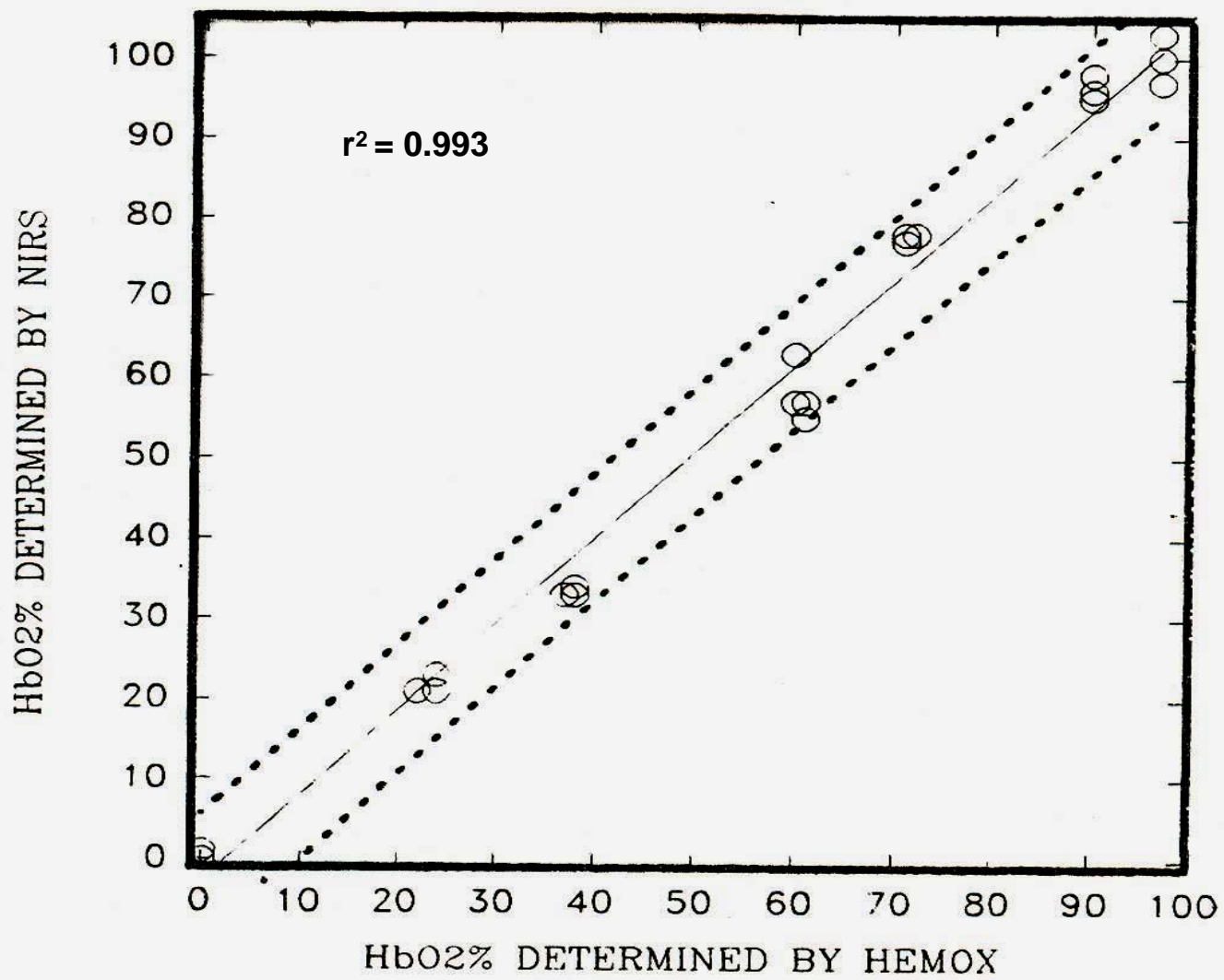




Derivation of Algorithm

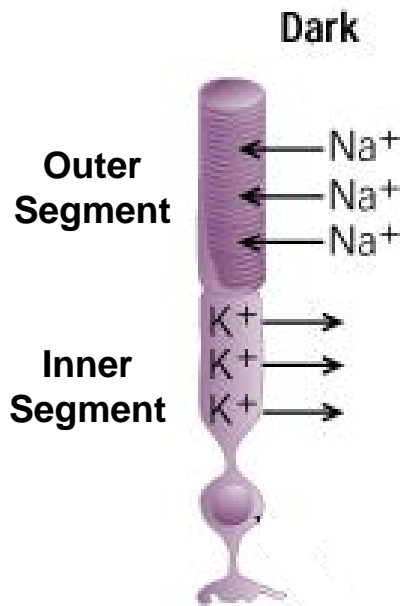
Consulted References

- R. Pittman and B. Duling (1975) described the relationship between spectral absorption and oxygen saturation of hemoglobin in microvasculature within visible range.
- A.P. Sheperd (1975) developed an empirically derived analytical expression relating OD and Hb concentration.
- Delori (1988) Determined contribution of fundus scattering to OD of hemoglobin at three wavelengths (555nm).
- Ferrari et al (1989) utilized DNIRS to noninvasively determine cerebral venous Hb saturation (sagittal sinus).

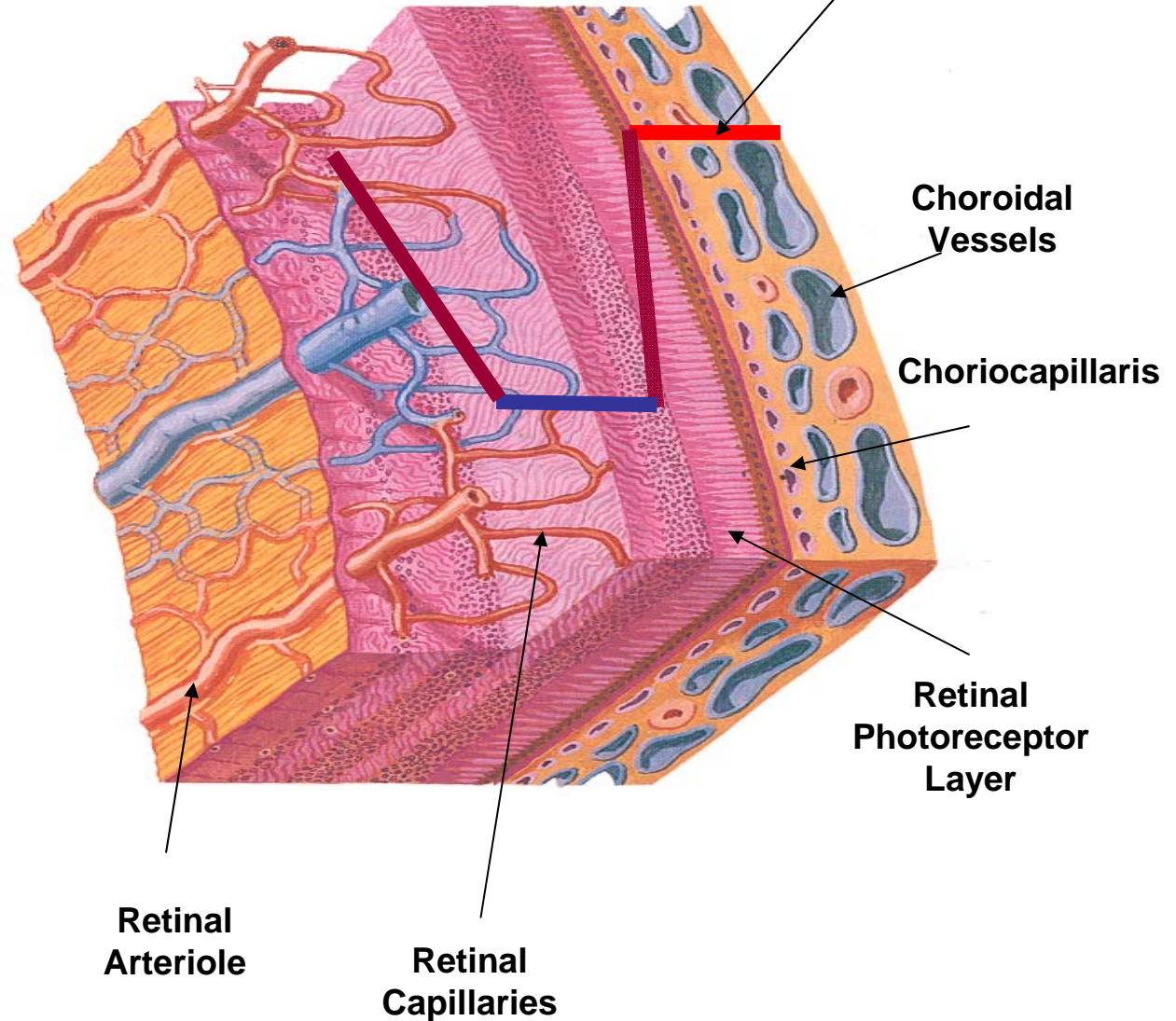


Dark Adapted—High Oxygen Extraction

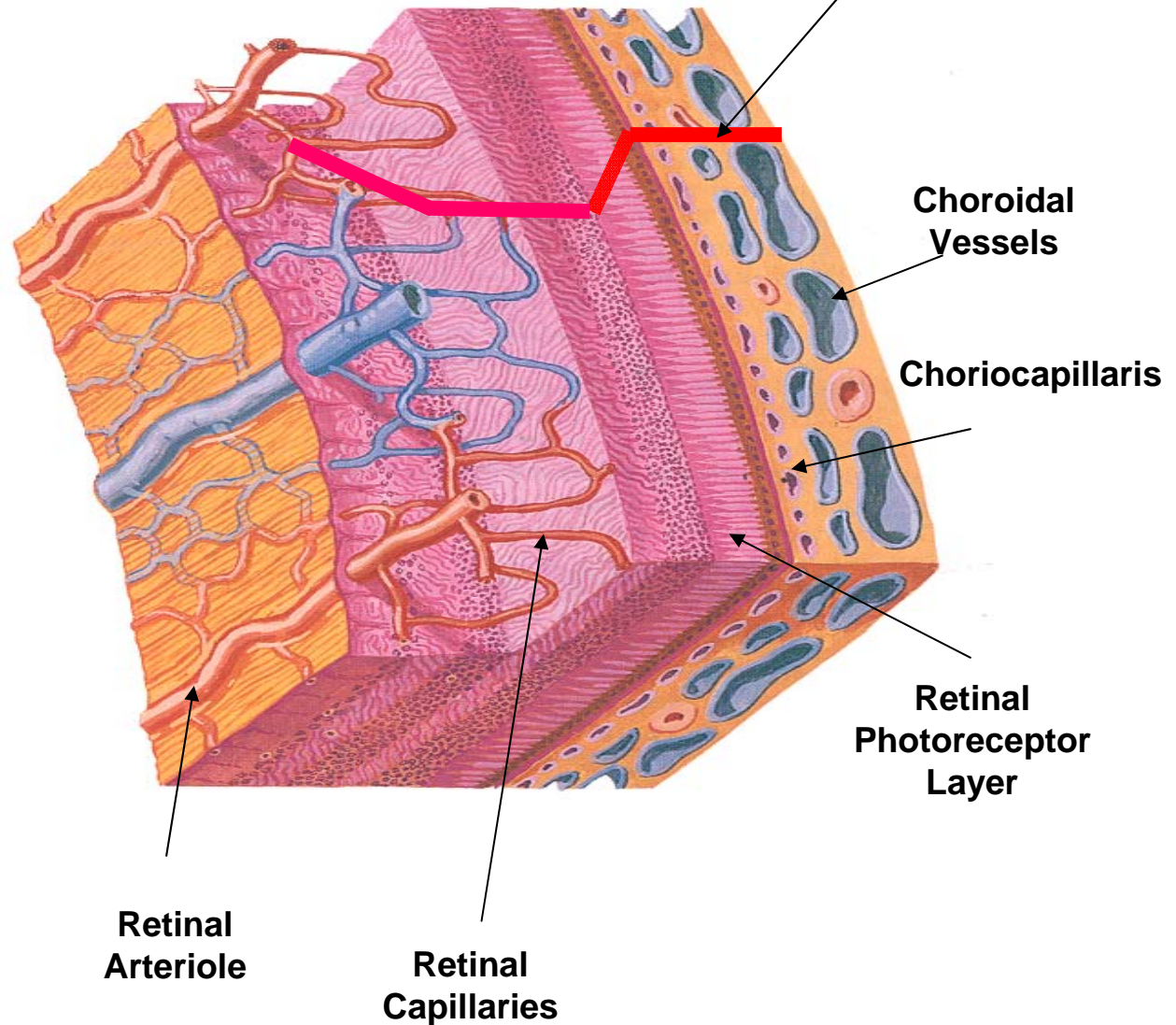
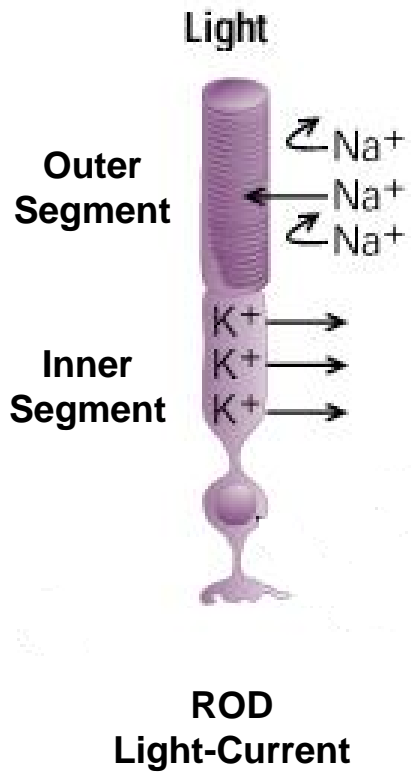
Profile of Oxygen Tension

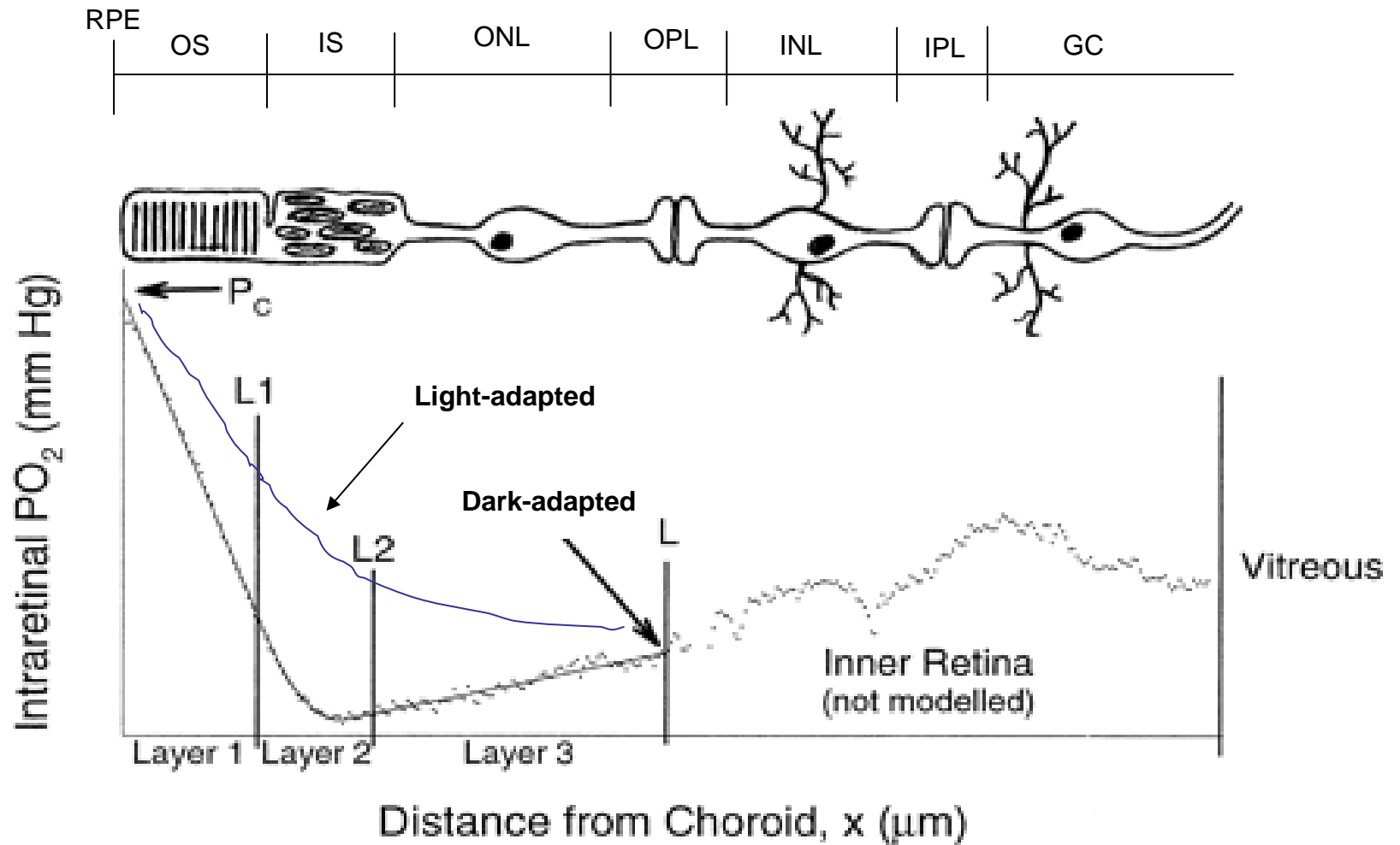


ROD
Dark-Current

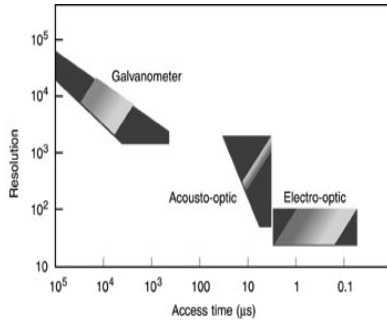


Light Adapted—Low Oxygen Extraction





In Situ Schematics of Optical System



**Electro-optic
or Acousto-optic
Deflector Device**

Detector

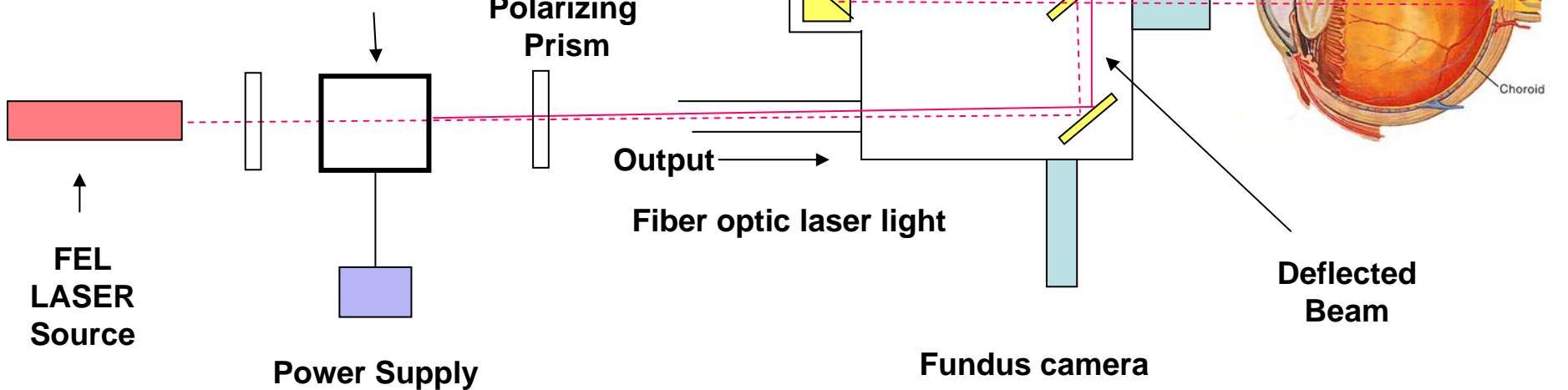
**Polarizing
Prism**

Output

Fiber optic laser light

Fundus camera

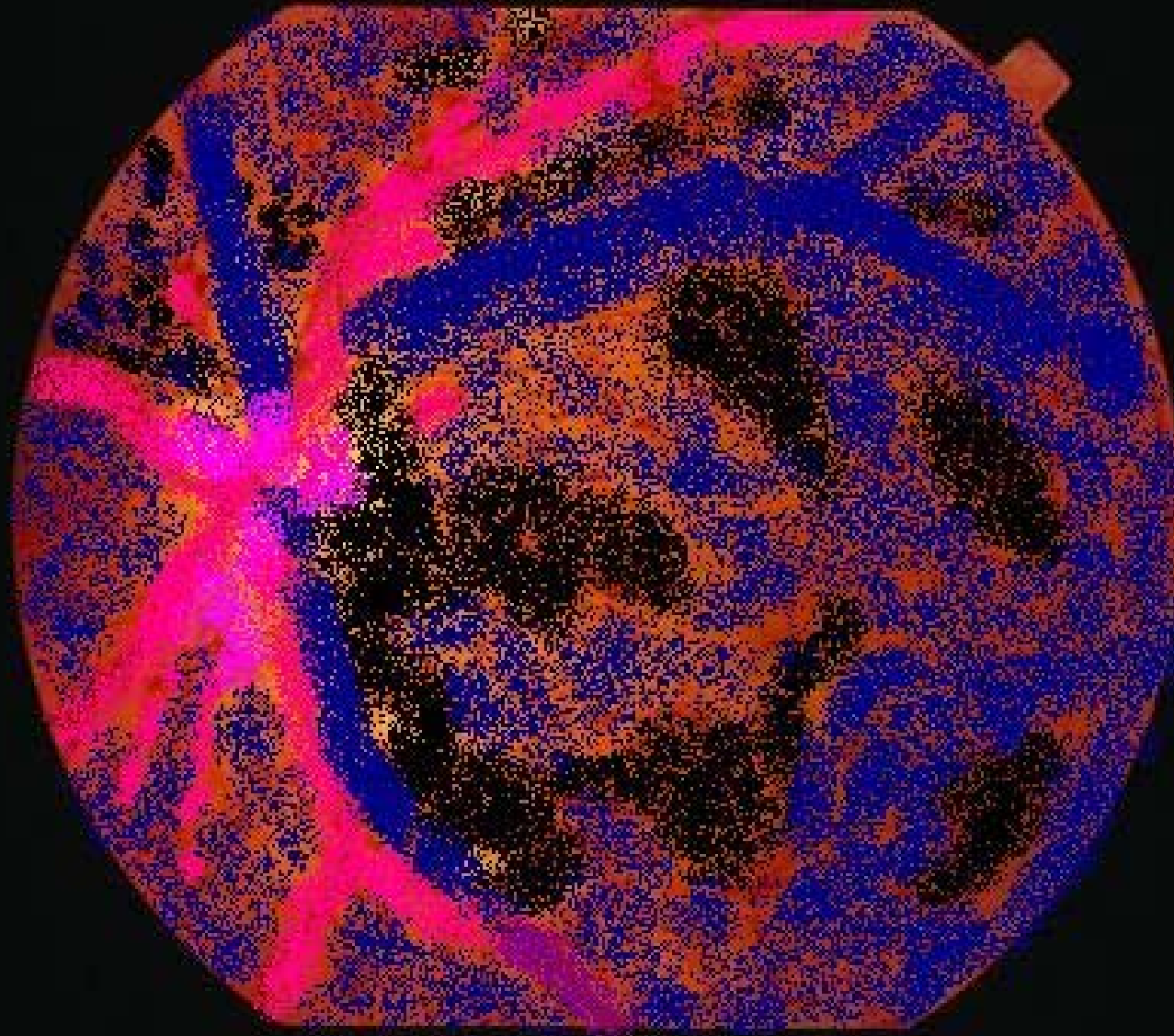
**Deflected
Beam**





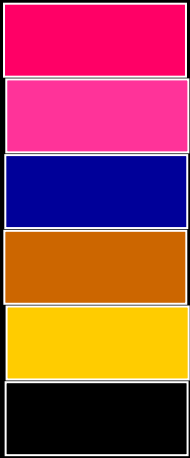
Regional Oxygen Map

Y



X

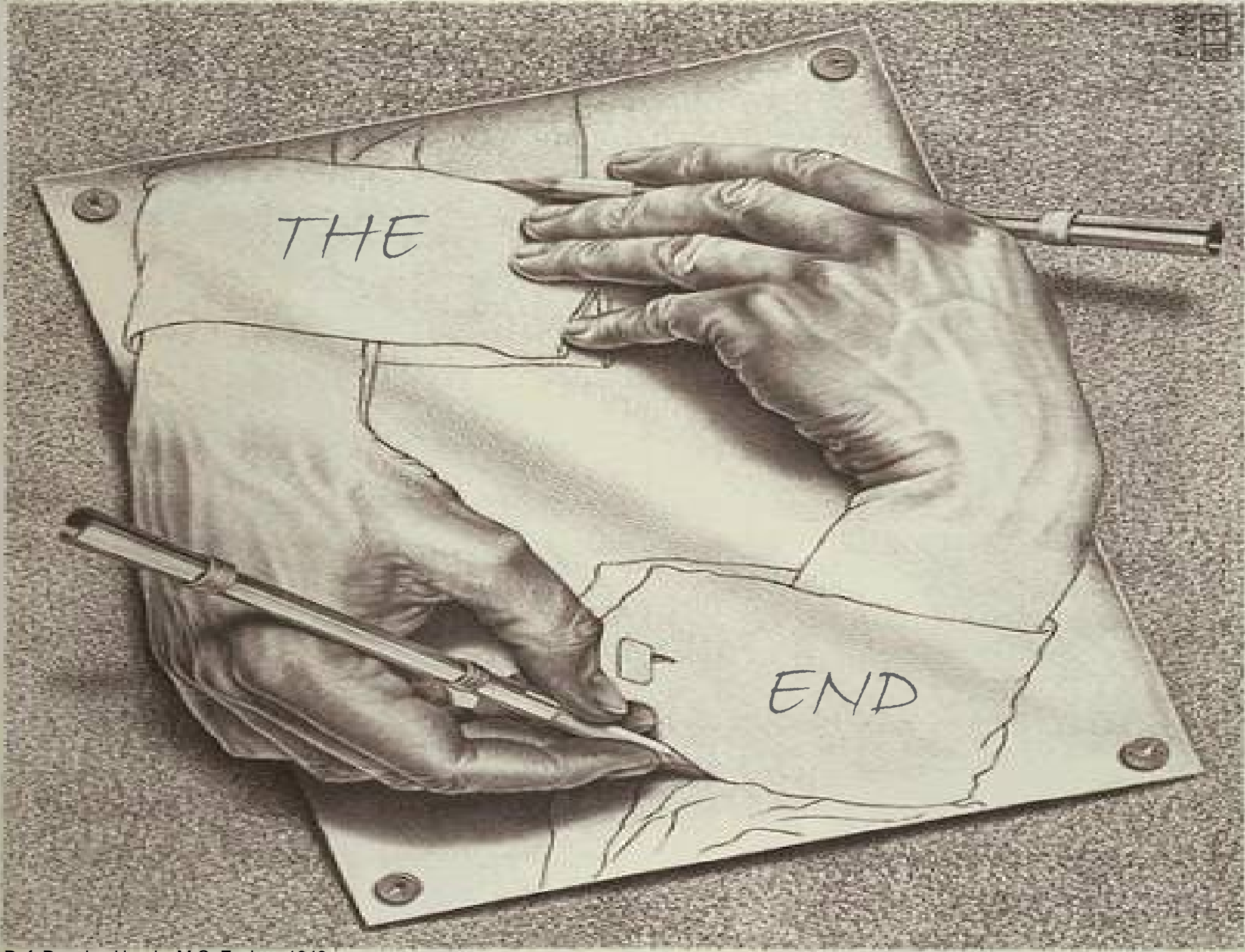
High O₂



Low O₂

Summary

- Presents the opportunity to study retinal metabolism in a yet unprecedented fashion.
- Technique may reveal subtle alterations in retinal metabolism that are not discernable with present routine function tests.
- Could promote a more rational physiologic basis for clinical intervention and delve into the pathogenic mechanisms and possible early diagnosis of diabetic retinopathy, and other retinal ischemic/vascular diseases.
- Collectively these retinopathies comprise the leading causes of blindness in the industrialized world.



Ref: Drawing Hands, M.C. Escher, 1948